

1. A microlithographic mask for forming a sub-resolution feature in photoresist with an acceptable process latitude, said mask comprising:
a layer of transparent material;
a layer of light-obstructing material; and
5 a layer of attenuating phase shifting material located between said layer of transparent material and said layer of light-obstructing material; and
wherein said layer of light-obstructing material and said layer of attenuating phase shifting material are patterned to form a transparent hole, a partially transmissive assist feature, and a light-obstructing frame located between
10 said transparent hole and said partially transmissive assist feature.

2. The mask of claim 1, wherein said transparent hole is a rectangle.

3. The mask of claim 2, wherein said light-obstructing frame includes an opaque frame, and wherein said opaque frame surrounds said transparent hole.

4. The mask of claim 3, wherein said partially transmissive feature includes a partially transmissive frame surrounding said opaque frame.

20 5. The mask of claim 4, wherein said layer of light-obstructing material includes a layer of opaque material, and wherein said layer of opaque material includes an opaque background surrounding said partially transmissive frame.

25 6. The mask of claim 1, wherein said layer of transparent material includes quartz.

7. The mask of claim 6, wherein said layer of attenuating phase shifting material includes a material selected from the group consisting of MoSi, chromium fluoride, silicon nitride, titanium nitride, tantalum silicide and zirconium silicon oxide.

8. The mask of claim 7, wherein said attenuating phase shifting material is deposited on said quartz.

5 9. The mask of claim 7, wherein the transmissivity of said layer of attenuating phase shifting material relative to said layer of transparent material is in the range of from about 6% to 100%.

10 10. The mask of claim 7, wherein said layer of light-obstructing material includes chrome.

15 11. The mask of claim 1, further comprising a partially transmissive frame, said layer of phase-shifting material being located between said transparent opening and partially transmissive frame.

20 12. A mask for forming a contact hole with a depth of focus of at least 0.4 μm , said mask comprising:

 a first layer of material; and

 a second layer of attenuating phase shifting material; and

25 wherein said first layer of material and said second layer of attenuating phase shifting material are patterned to form a transparent opening, a partially transmissive rim surrounding said opening, and sub-resolution assist features for preventing incident light from propagating through portions of said attenuating phase shifting material.

25 13. The mask of claim 12, wherein said partially transmissive rim is arranged to phase shift said incident light by 180° or an odd multiple of 180° .

14. The mask of claim 13, wherein said sub-resolution assist features form polygonal corners on said partially transmissive rim.

15. The mask of claim 14, wherein said polygonal corners include square corners.

5 16. The mask of claim 14, wherein said polygonal corners form triangular corners.

10 17. The mask of claim 12, further comprising at least one opaque frame.

18. The mask of claim 12, further comprising at least one transparent frame.

19. The mask of claim 12, further comprising at least one opaque frame surrounding said partially transmissive rim.

15 20. The mask of claim 19, further comprising bars with ends that do not overlap each other.

20 21. The mask of claim 12, further comprising at least one transparent frame surrounding said partially transmissive frame.

22. The mask of claim 21, wherein said transparent frame is formed of bars with ends that do not overlap each other.

25 23. A microlithographic mask, comprising:

transparent material; and

patterned opaque material and phase shifting material, said patterned materials defining an opening, an opaque frame surrounding said opening, sub-resolution bars surrounding said frame, and opaque corners located between sub-resolution bars.

24. The mask of claim 23, wherein said transparent material includes quartz.

5 25. The mask of claim 24, wherein said phase shifting material is partially transmissive relative to said transparent material.

10 26. The mask of claim 25, wherein said opaque material includes metal deposited on said phase shifting material.

15 27. The mask of claim 23, further comprising an opaque frame surrounding said sub-resolution bars, and partially transmissive bars surrounding said opaque frame.

20 28. A mask for forming an array of sub-resolution features, said mask comprising:

 a layer of transparent material;

 a layer of light-obstructing material; and

 a layer of attenuating phase shifting material located between said layer of transparent material and said layer of light-obstructing material; and

 wherein said layer of light-obstructing material and said layer of attenuating phase shifting material are patterned to form transparent holes and light-obstructing frames surrounding said transparent holes.

25 29. The mask of claim 28, further comprising partially transmissive features surrounding said light-obstructing frames.

 30. The mask of claim 29, further comprising opaque corners on said partially transmissive features.

31. A multi-tone mask for forming sub-resolution features, said mask comprising:

a first layer of attenuating phase shifting material, said layer defining openings corresponding to said sub-resolution features; and

5 a second layer of material for preventing incident light from propagating through said first layer, said second layer including frames surrounding said openings, and wherein said second layer defines bar-shaped partially transmissive assist features.

10 32. The mask of claim 31, wherein phase-shifted light transmitted through one of said bars operatively interacts with light transmitted through said openings.

15 33. A mask for forming an elliptical feature in photoresist, said mask comprising:

a layer of opaque material; and

a layer of attenuating phase shifting material located between said layer of transparent material and said layer of opaque material; and

20 wherein said layer of opaque material and said layer of attenuating phase shifting material are patterned to form transparent holes and opaque frames surrounding said transparent holes.

25 34. The mask of claim 33, further comprising an array of rectangular openings, and attenuating phase shifting bars located between said rectangular openings.

35. The mask of claim 34, further comprising a patterned layer of opaque material for defining said attenuating phase shifting bars.

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36. The mask of claim 35, further comprising a transparent substrate for supporting said attenuating phase shifting bars and said patterned layer of opaque material.

5 37. A method of making a multi-tone microlithographic mask, said method comprising:

providing sets of dimension data representative of mask patterns;
for each set of dimension data, calculating feature dimension data as a function of optical conditions; and

10 for a desired optical condition, identifying the sets of dimension data that have feature dimension data within desired limits.

15 38. The method of claim 37, further comprising the step of selecting the one set of dimension data that achieves the smallest change in critical dimension between a zero defocus condition and a maximum considered defocus condition.

20 39. The method of claim 38, wherein said dimension data includes the widths of transparent openings in said patterns.

25 40. The method of claim 39, wherein said dimension data includes sub-resolution dimensions of opaque features in said patterns.

41. The method of claim 40, wherein said dimension data includes dimensions of partially transmissive phase shifting features in said patterns.

25 42. The method of claim 41, wherein said limits include a critical dimension for an exposed feature.

30 43. The method of claim 42, wherein said limits operate to exclude sidelobing conditions.

44. The method of claim 43, further comprising the step of forming patterned layers of attenuating phase shifting material and light-obstructing material in accordance with said one set of dimension data.

5 45. The method of claim 44, wherein said light-obstructing material includes opaque material.

10 46. The method of claim 44, wherein said light-obstructing material includes partially transmissive material.

15 47. The method of claim 37, wherein said feature dimension data define opaque corner structures.

48. The method of claim 37, wherein said feature dimension data define partially transmissive corner structures.

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